Tropical ocean decadal variability and connections to Antarctic and Arctic sea ice

Gerald Meehl

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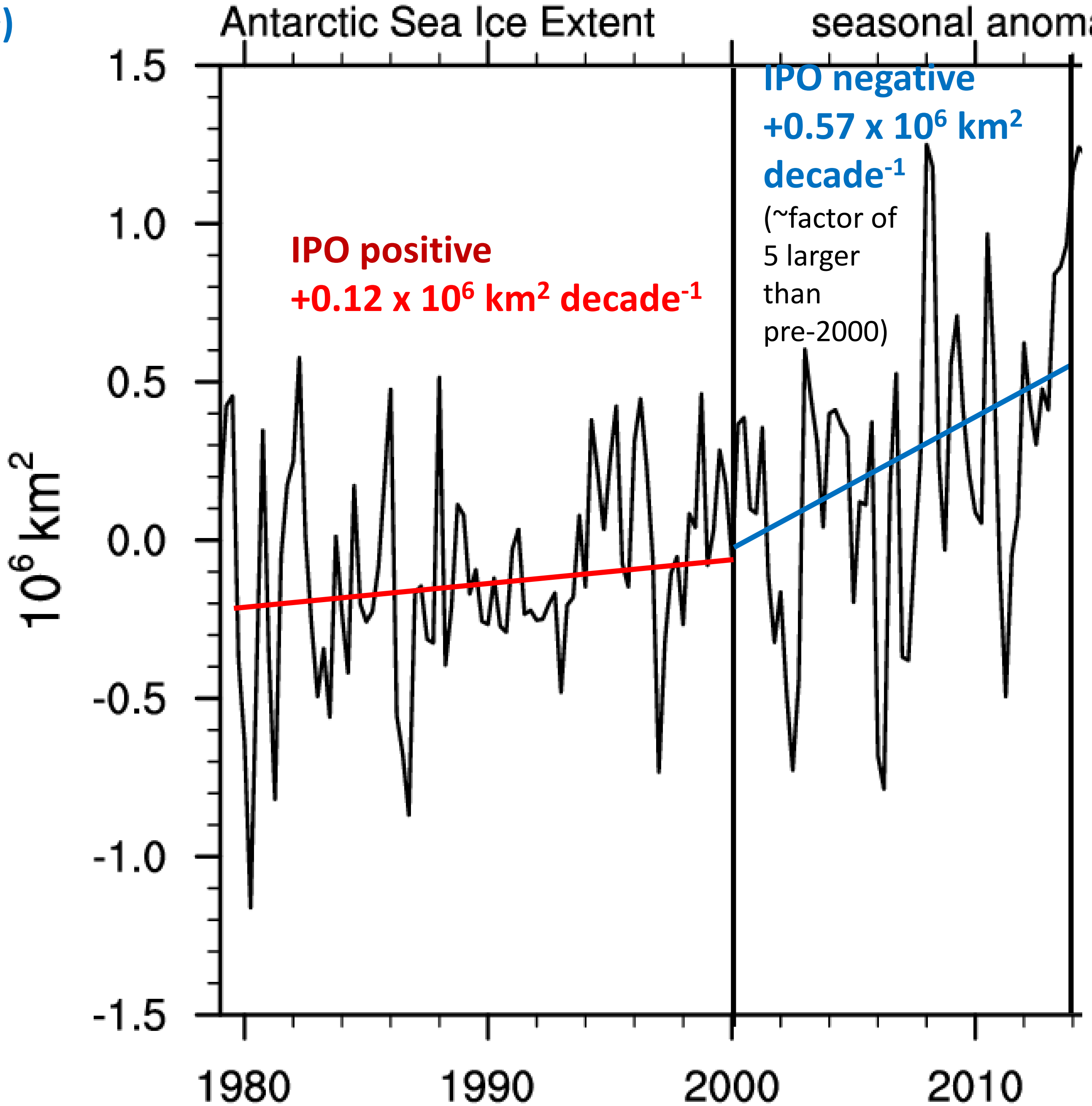
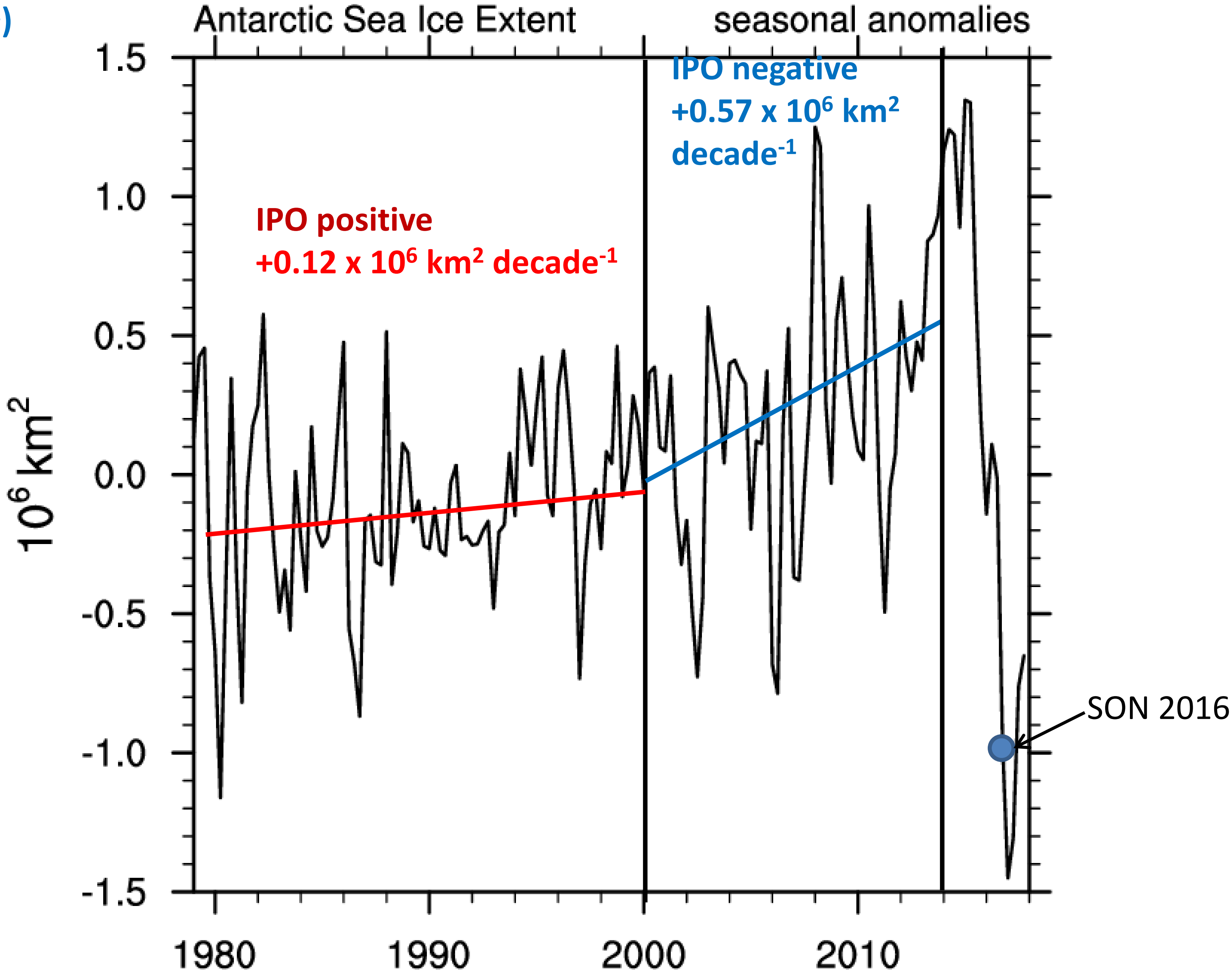
annual mean Antarctic sea-ice extent from 2000-2014 (linear trend of $+0.57 \times 10^6$ km^2 $decade^{-1}$) about a factor of five larger than the increase from 1979-1999 (linear trend of $+0.12 \times 10^6$ km^2 $decade^{-1}$)



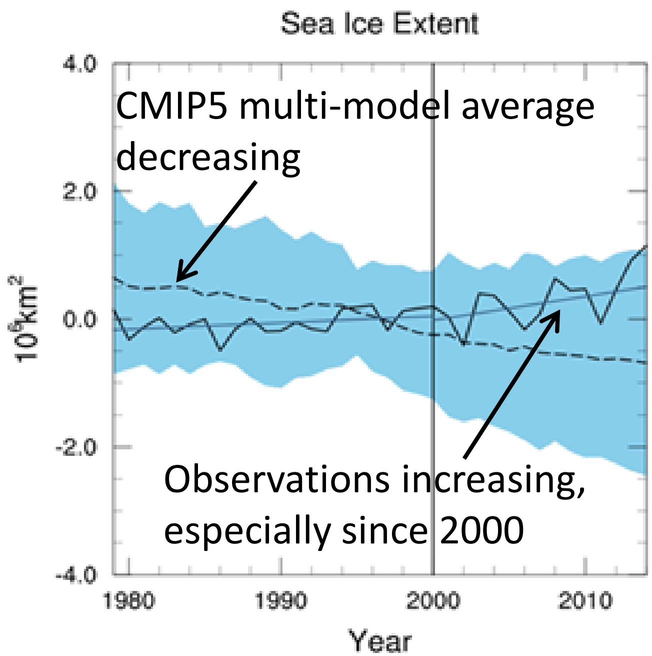
(Meehl, Arblaster, Bitz, Chung, and Teng, 2016, Nature Geoscience) annual mean Antarctic sea-ice extent from 2000-2014 (linear trend of $+0.57 \times 10^6$ km^2 decade^{-1}) about a factor of five larger than the increase from 1979-1999 (linear trend of $+0.12 \times 10^6$ km^2 decade^{-1})



--Increases in observed Antarctic sea-ice extent accelerated from the late 1990s to 2014

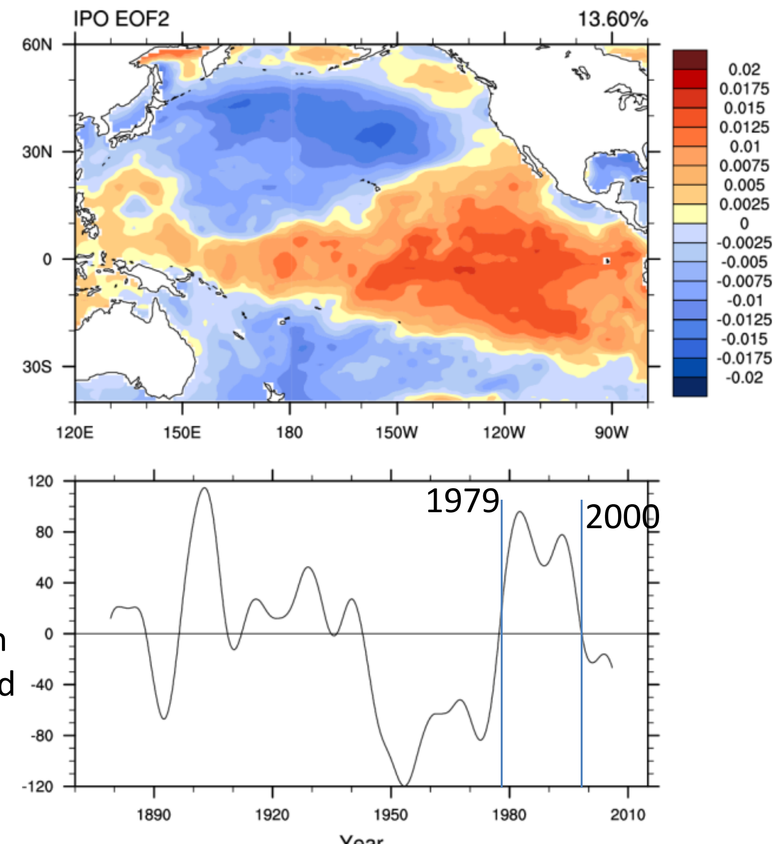
--The average of all climate models shows a decline

--**Are the models wrong, or can natural variability associated with the Interdecadal Pacific Oscillation (IPO) be playing a role?**



linear trend 1979-1999: $+0.12 \times 10^6$ km^2 decade^{-1}

2000-2014: $+0.57 \times 10^6$ km^2 decade^{-1}



Observed IPO pattern (top, sign convention for positive IPO) and PC time series index (bottom)

(Meehl, Arblaster, Bitz, Chung, and Teng, 2016, Nature Geoscience)

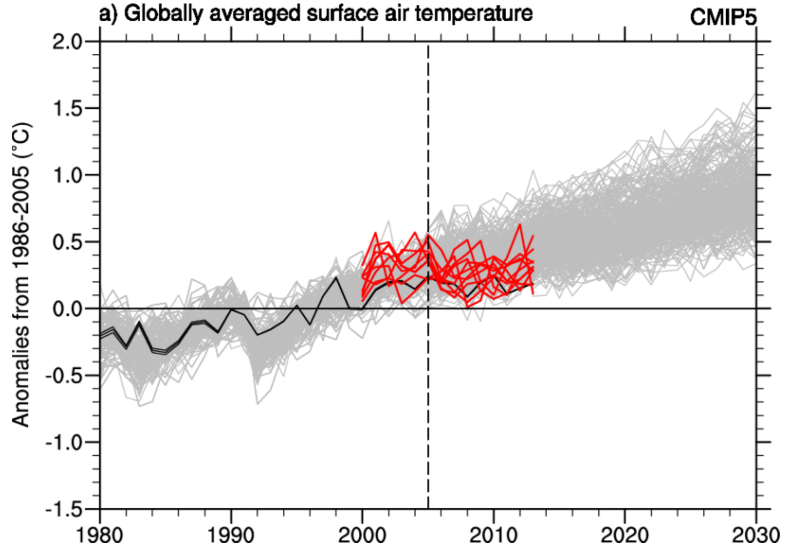
Slowdown as observed from 2000-2013:
10 members out of 262 possible realizations

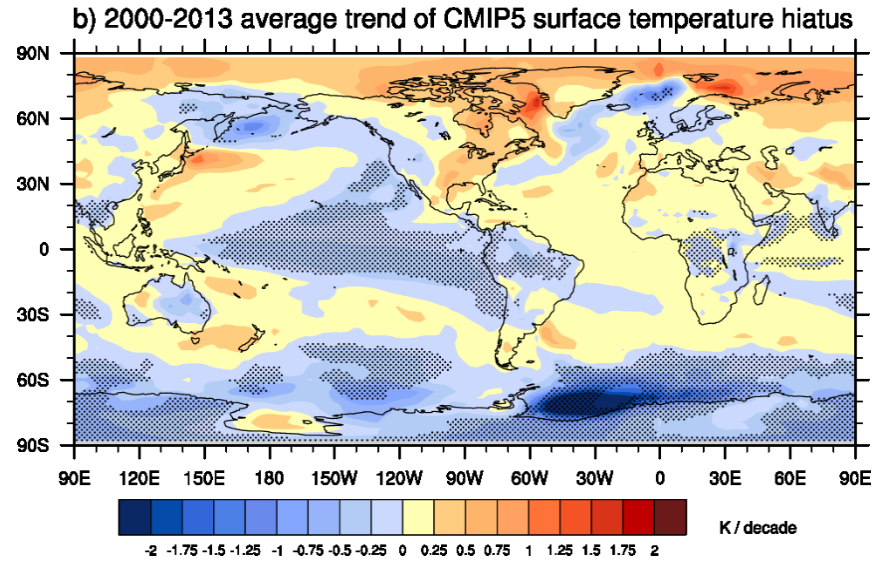
Some CMIP5 uninitialized models actually simulated the slowdown as observed

Characterized by a **negative phase of the IPO**

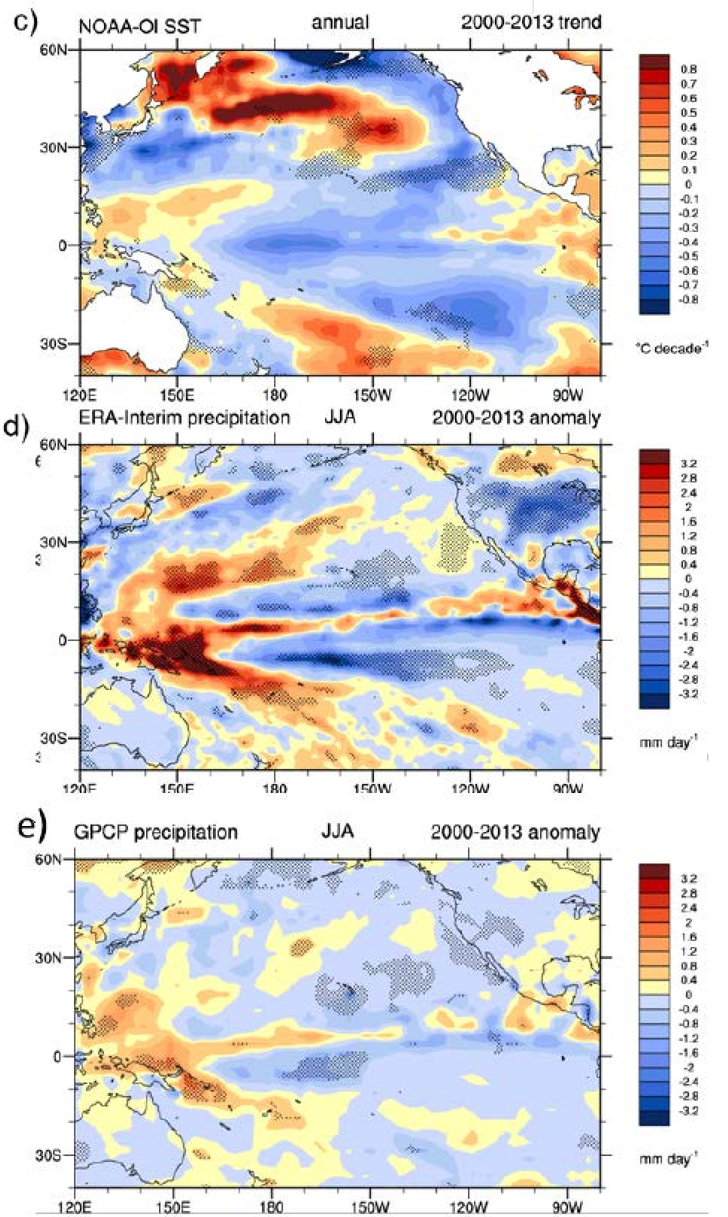
internally generated variability in those model simulations happened to sync with observed internally generated variability

(Meehl et al., 2014, Nature Climate Change)

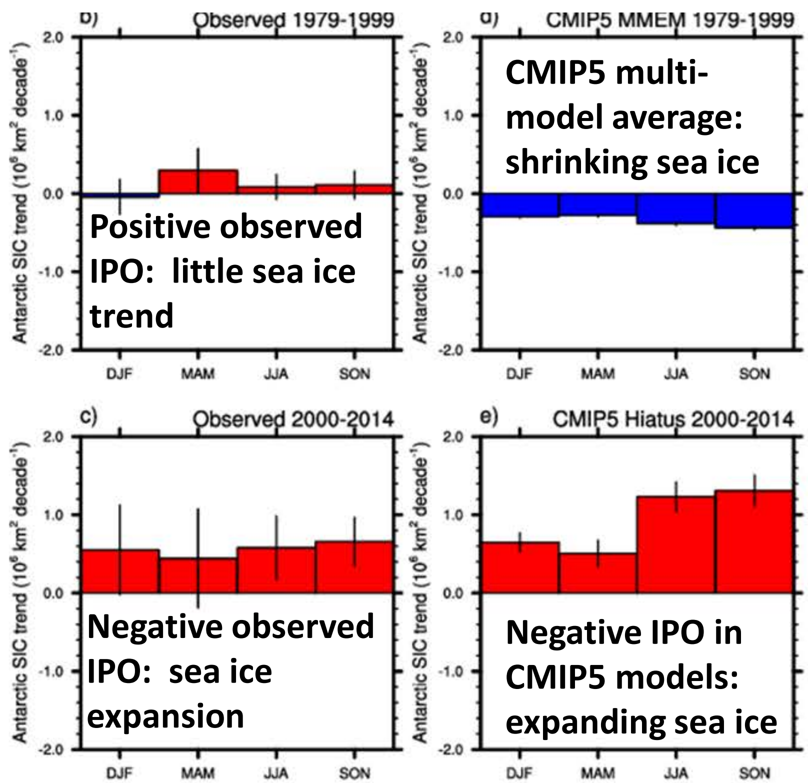




Negative IPO: tropical Pacific SSTs cooler, negative precipitation and convective heating anomalies, and expanding Antarctic sea ice



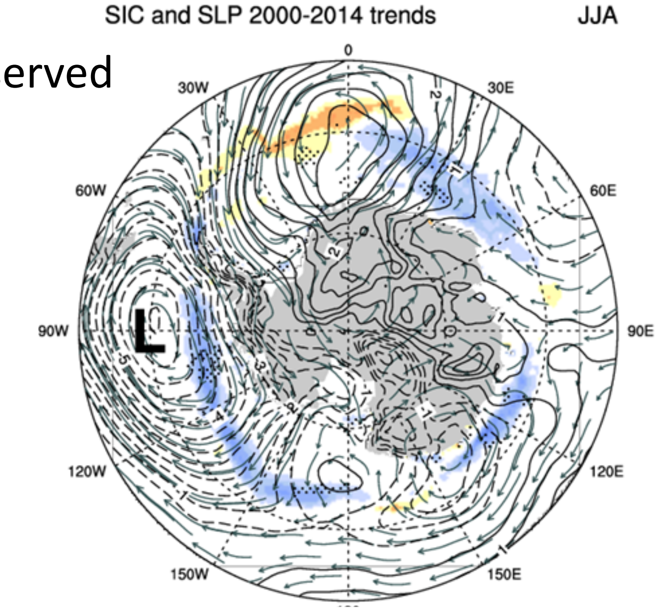
Observed SST trend, 2000-2013 (top) and two estimates of precipitation anomaly, 2000-2013 (middle and bottom)



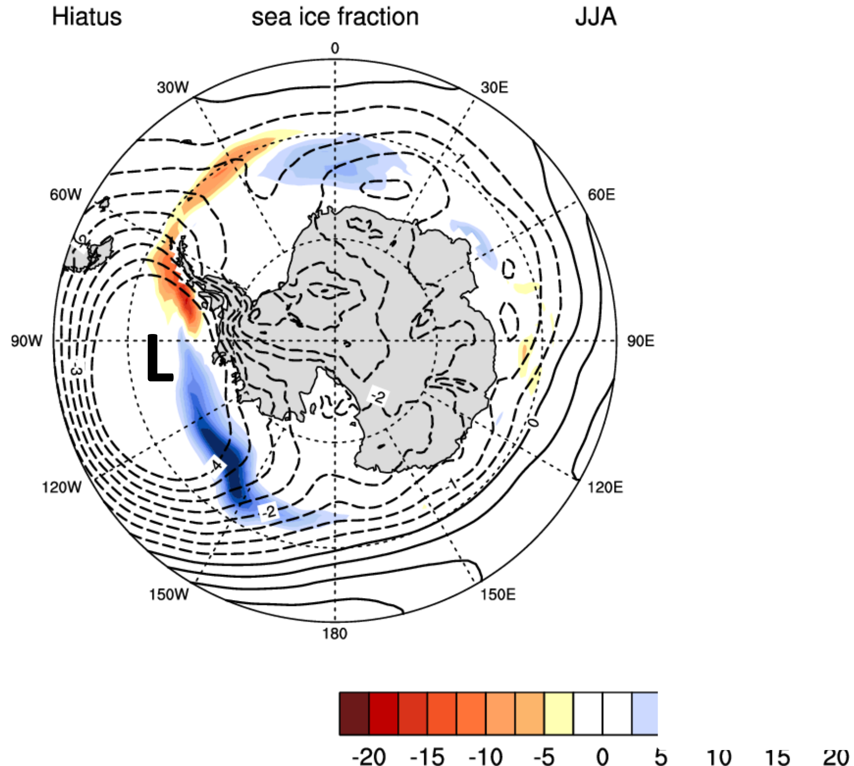
(Meehl et al., 2016, Nature Geo.)

Negative IPO: observed deepening of Amundsen Sea Low, and expanding Antarctic sea ice since 2000 driven by equatorward surface winds

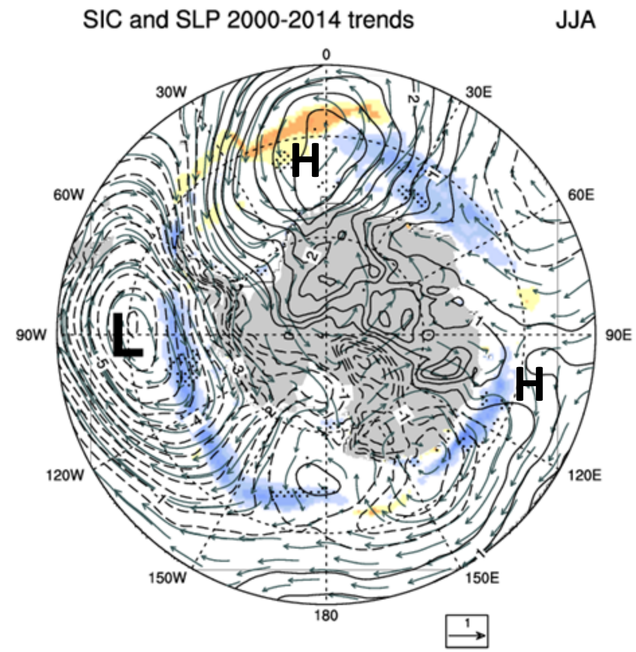
Observed



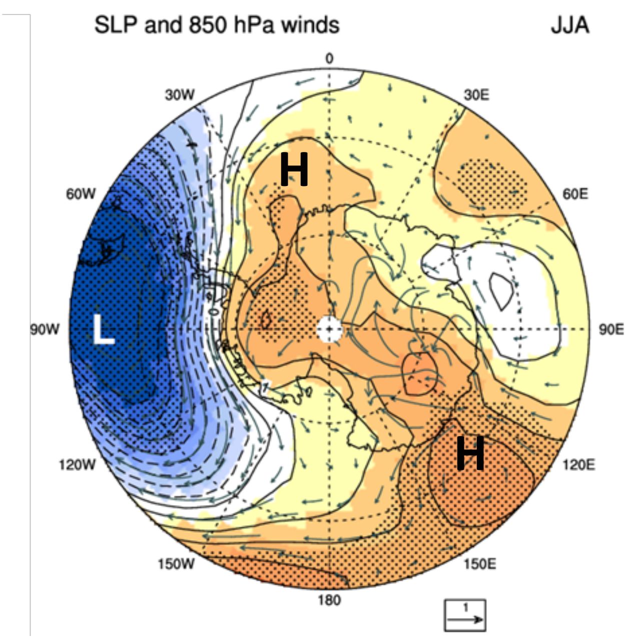
Model simulations with negative IPO 2000-2013



Negative IPO: observed deepening of Amundsen Sea Low from 2000-2014, and expanding Antarctic sea ice since 2000 driven by equatorward surface winds

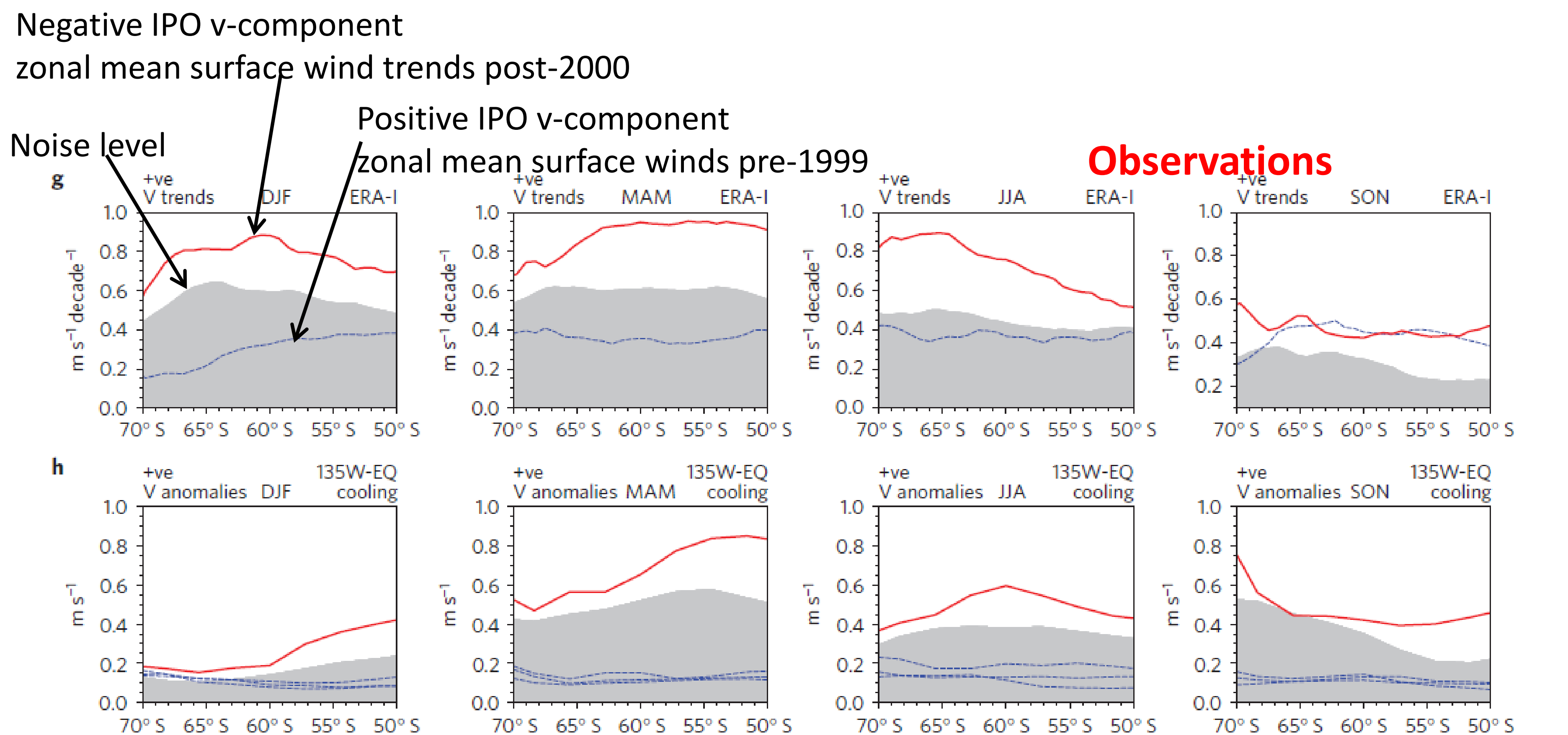


Model sensitivity experiment: IPO-related negative convective heating anomalies in eastern tropical Pacific (135W, Eq) produce deepened Amundsen Sea Low and preponderance of equatorward surface winds that expand Antarctic sea ice

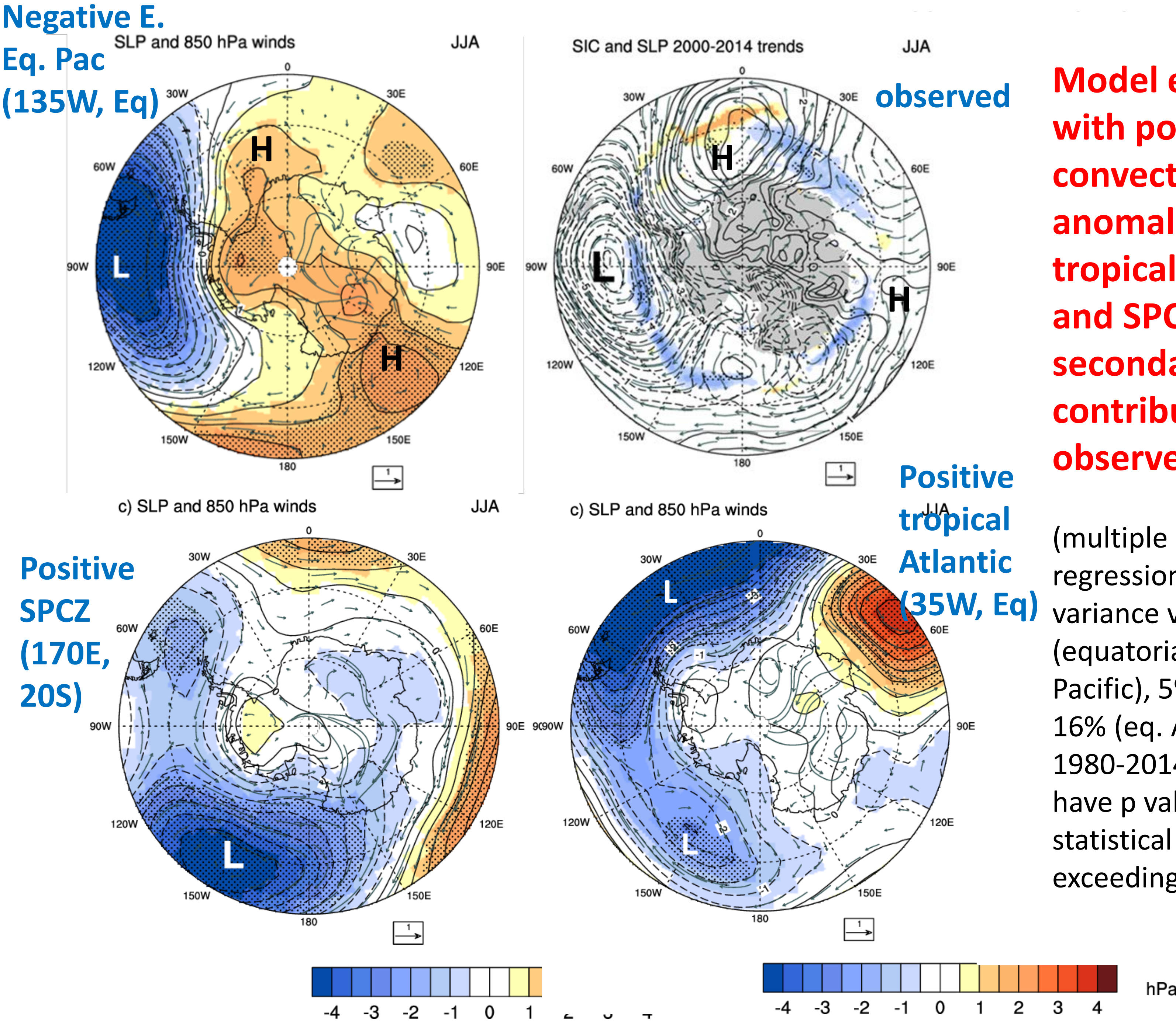


(only JJA shown here, other seasons show similar results)

Zonal mean v-component surface wind trends show significantly greater northward (positive) anomalies for negative IPO (observations, top) and for model simulation with specified negative convective heating anomaly in eastern equatorial Pacific representing negative IPO post-2000 (bottom)



Model (with specified negative convective heating anomaly in eastern eq. Pacific)

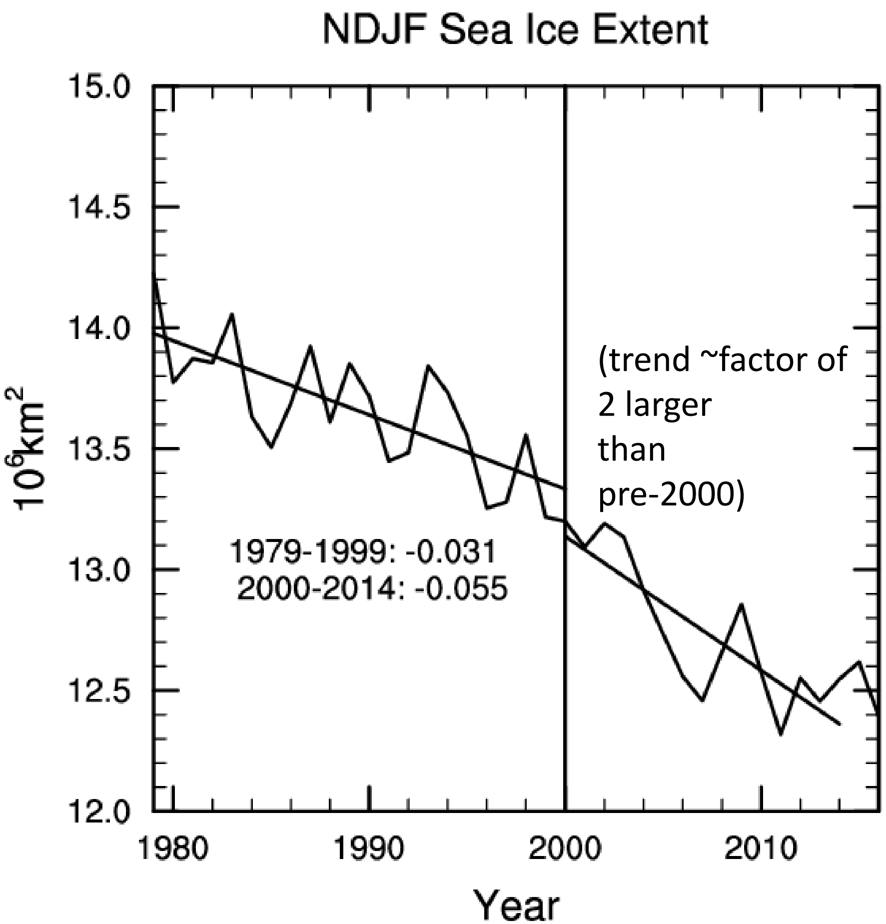


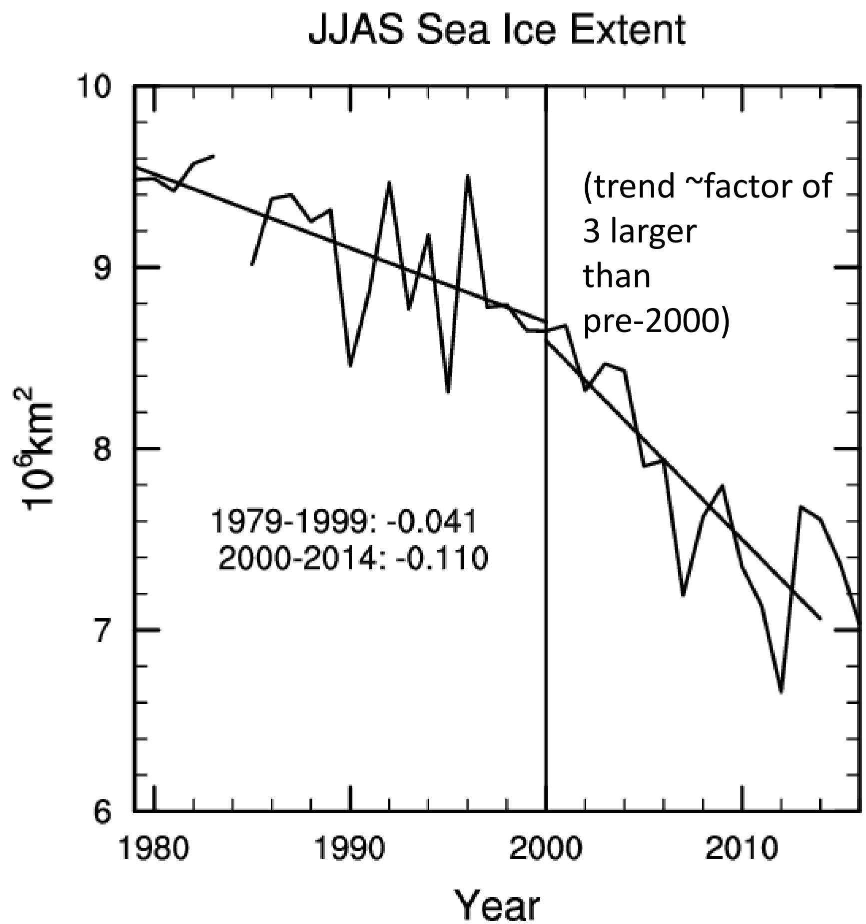
Model experiments with positive convective heating anomalies in tropical Atlantic and SPCZ are secondary contributors to the observed pattern

(multiple linear regression: r^2 explained variance values are 25% (equatorial eastern Pacific), 5% (SPCZ) and 16% (eq. Atlantic) for the 1980-2014 period. All have p values indicating statistical significance exceeding the 5% level)

Has decadal variability in the tropical oceans affected trends of Arctic sea ice extent?

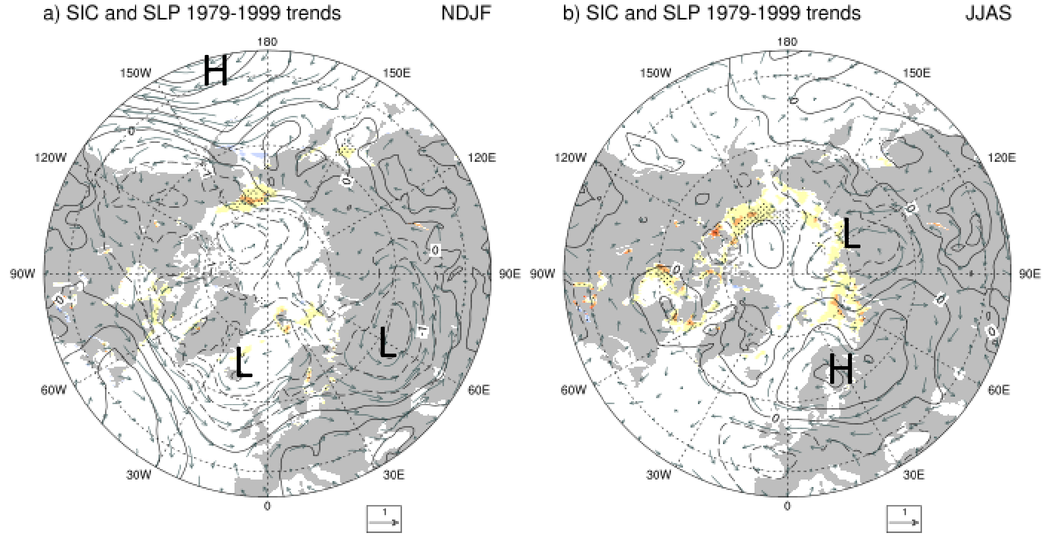
Arctic





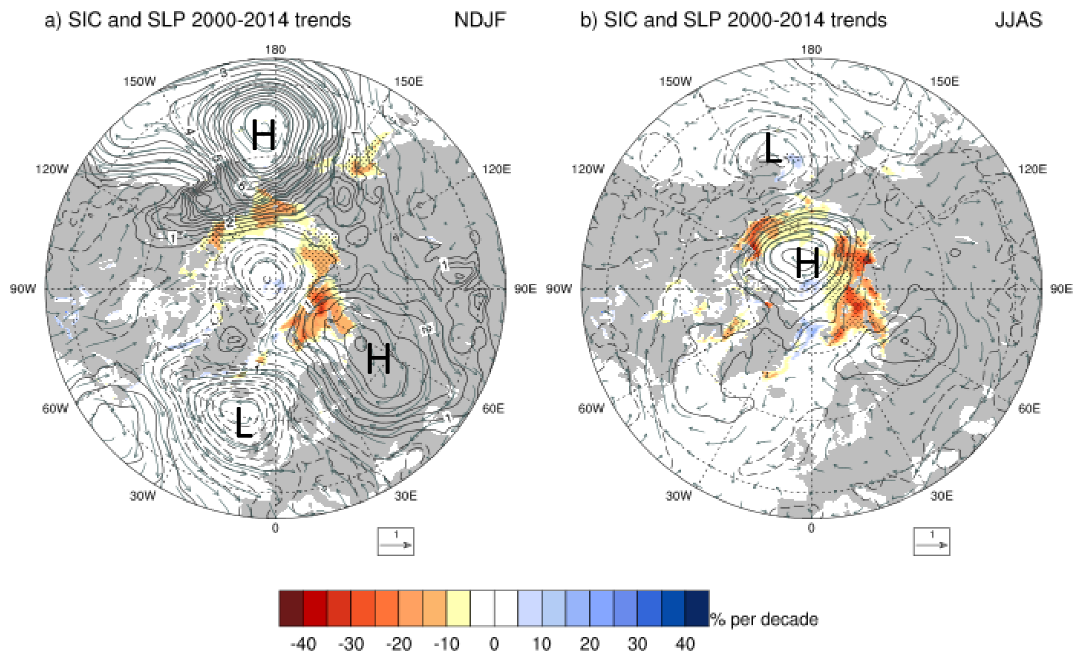
At the IPO transition around 2000, sea ice extent trends accelerate in both seasons (NDJF by nearly a factor of two, nearly a factor of three in JJAS)

Observed SLP and sea ice concentration trends 1979-1999

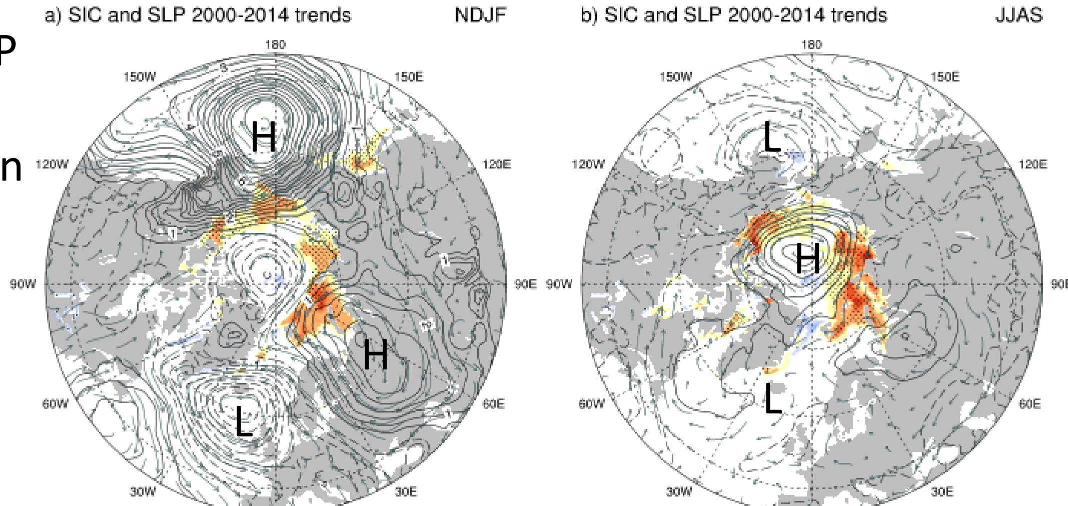


Marked difference in observed SLP trend patterns from 1979-99 (above) to 2000-2014 (below) in both seasons

Observed SLP and sea ice concentration trends 2000-2014



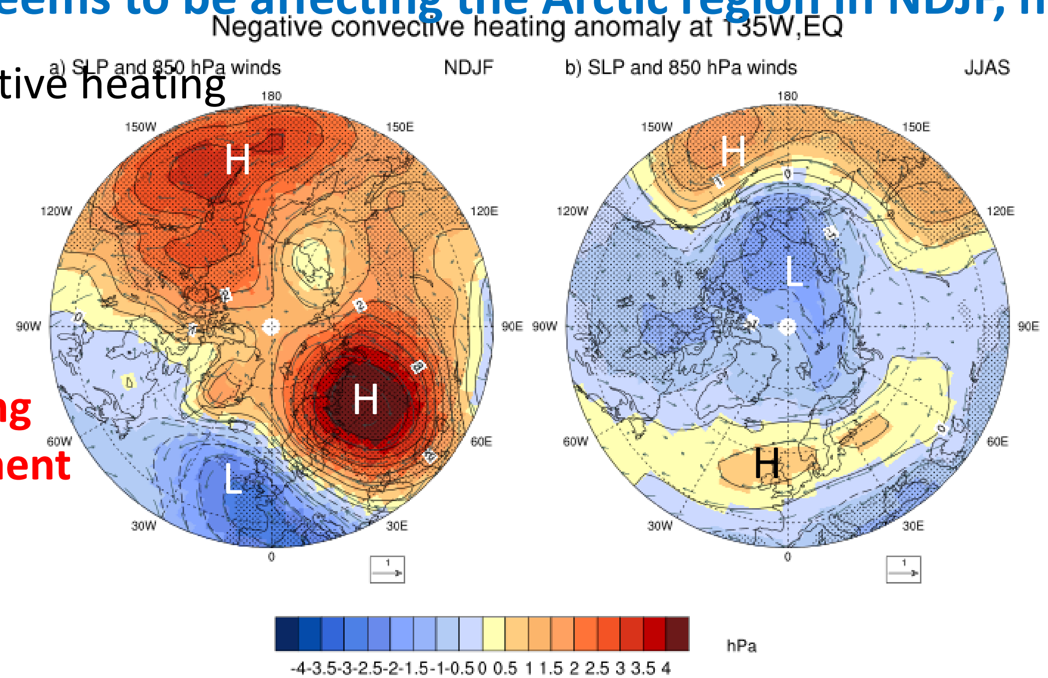
Observed SLP and sea ice concentration trends 2000-2014



2000-2014: qualitative agreement in pattern of observed SLP trends in NDJF for obs and negative IPO convective heating anomaly (left side); little agreement (actually opposite sign) of pattern from obs to model experiment in JJAS (right side); **forcing from Pacific seems to be affecting the Arctic region in NDJF, not JJAS**

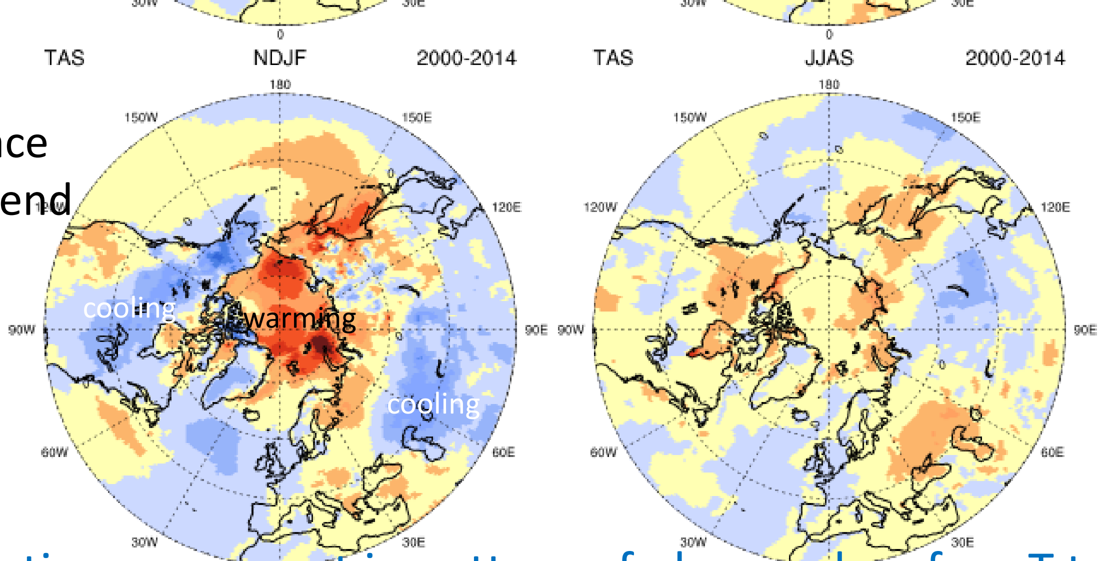
Negative convective heating anomaly Pacific (negative IPO) SLP

Negative Pacific convective heating anomaly experiment



Observed surface temperature trend 2000-2014

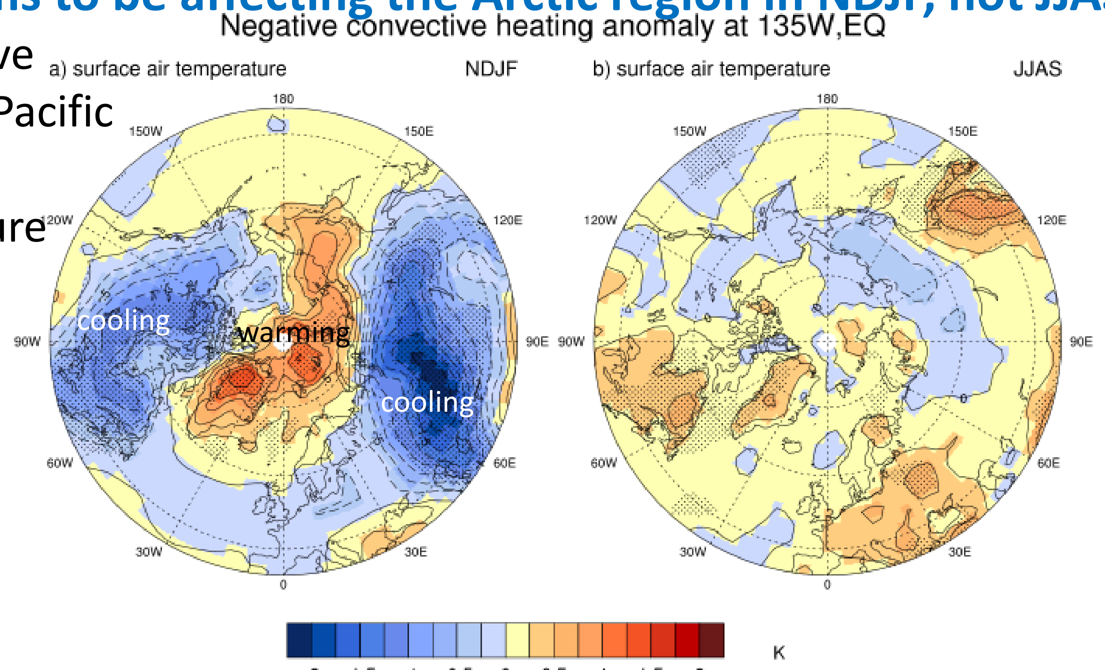
Surface temperature trends



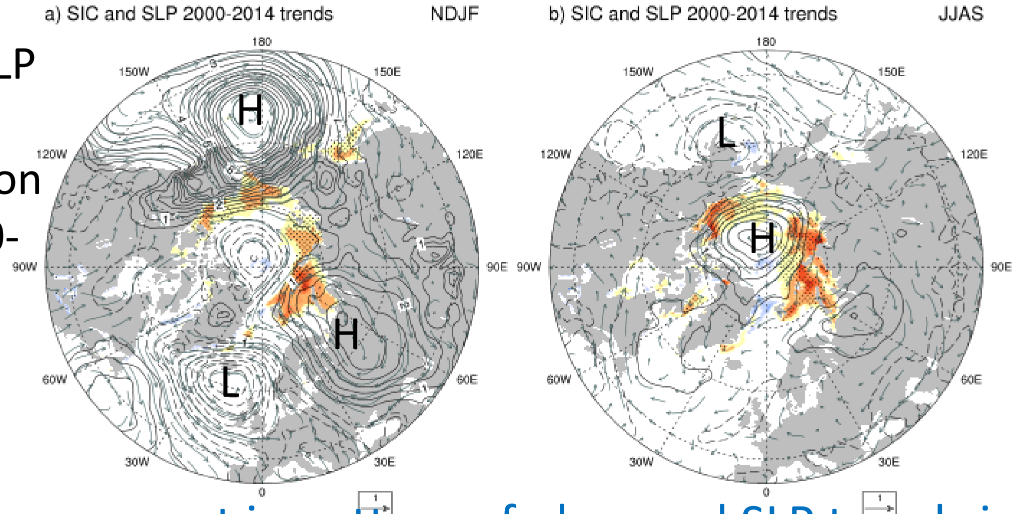
2000-2014: qualitative agreement in pattern of observed surface T trends in NDJF for obs and negative IPO convective heating anomaly (left side); little agreement in pattern from obs to model experiment in JJAS (right side). **Consistent with SLP, forcing from Pacific seems to be affecting the Arctic region in NDJF, not JJAS**

Negative convective heating anomaly, Pacific (negative IPO)

Surface temperature anomalies



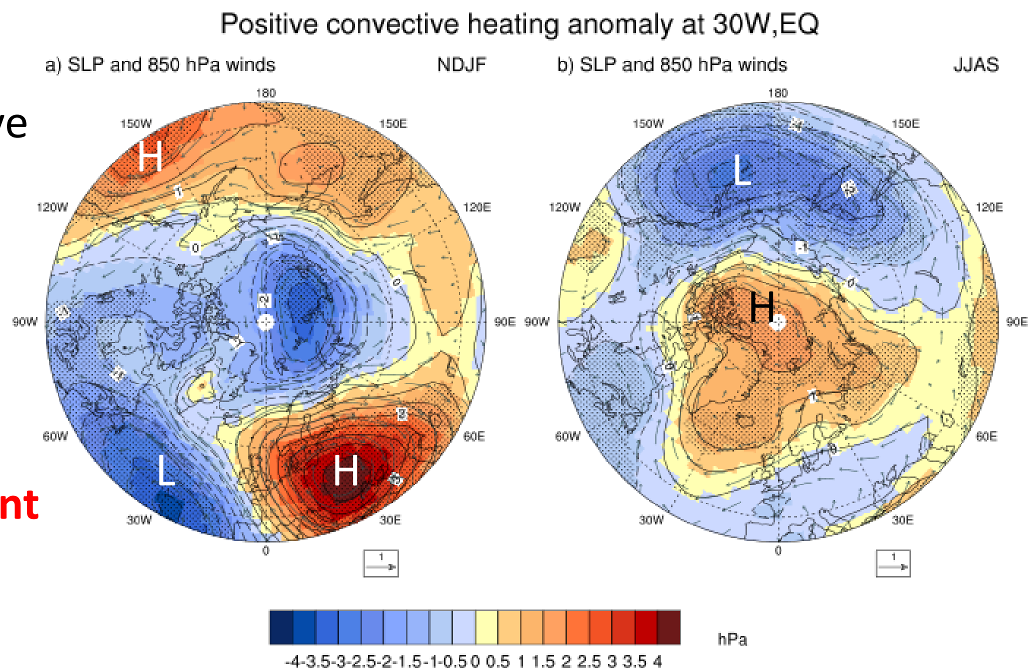
Observed SLP and sea ice concentration trends 2000-2014



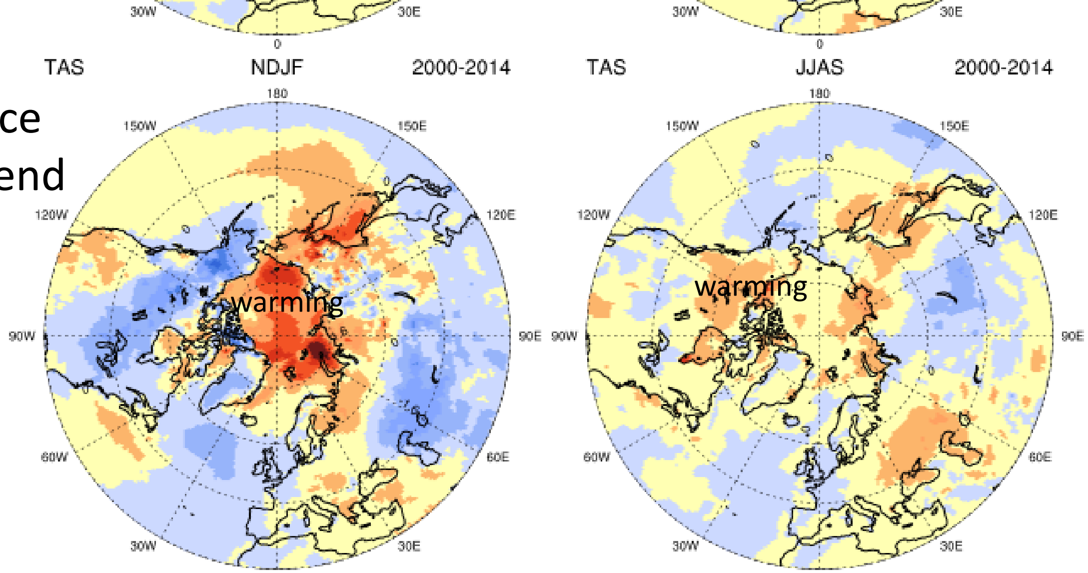
2000-2014: little agreement in pattern of observed SLP trends in NDJF for obs and positive Atlantic convective heating anomaly (left side); qualitative agreement in JJAS (right side); **forcing from Atlantic affecting the Arctic region JJAS, not NDJF**

Positive convective heating anomaly, Atlantic SLP

Positive Atlantic convective heating anomaly experiment



Observed surface temperature trend 2000-2014

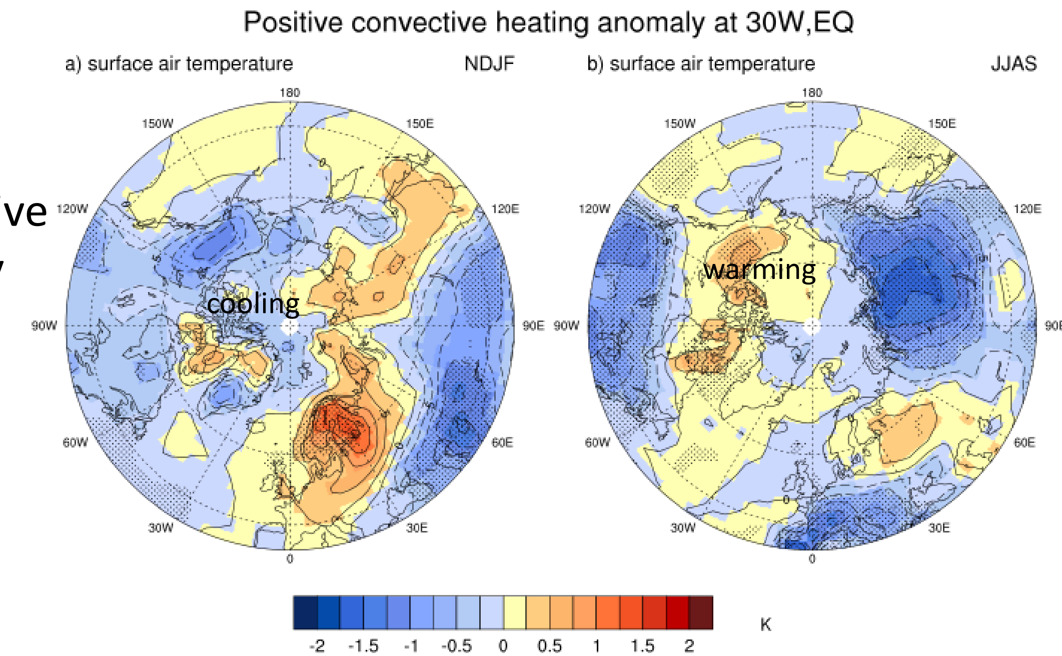


2000-2014: little agreement in pattern of observed surface T trends in NDJF for obs and positive Atlantic convective heating anomaly; qualitative agreement in JJAS.

Consistent with SLP, forcing from Atlantic affecting the Arctic region JJAS, not NDJF

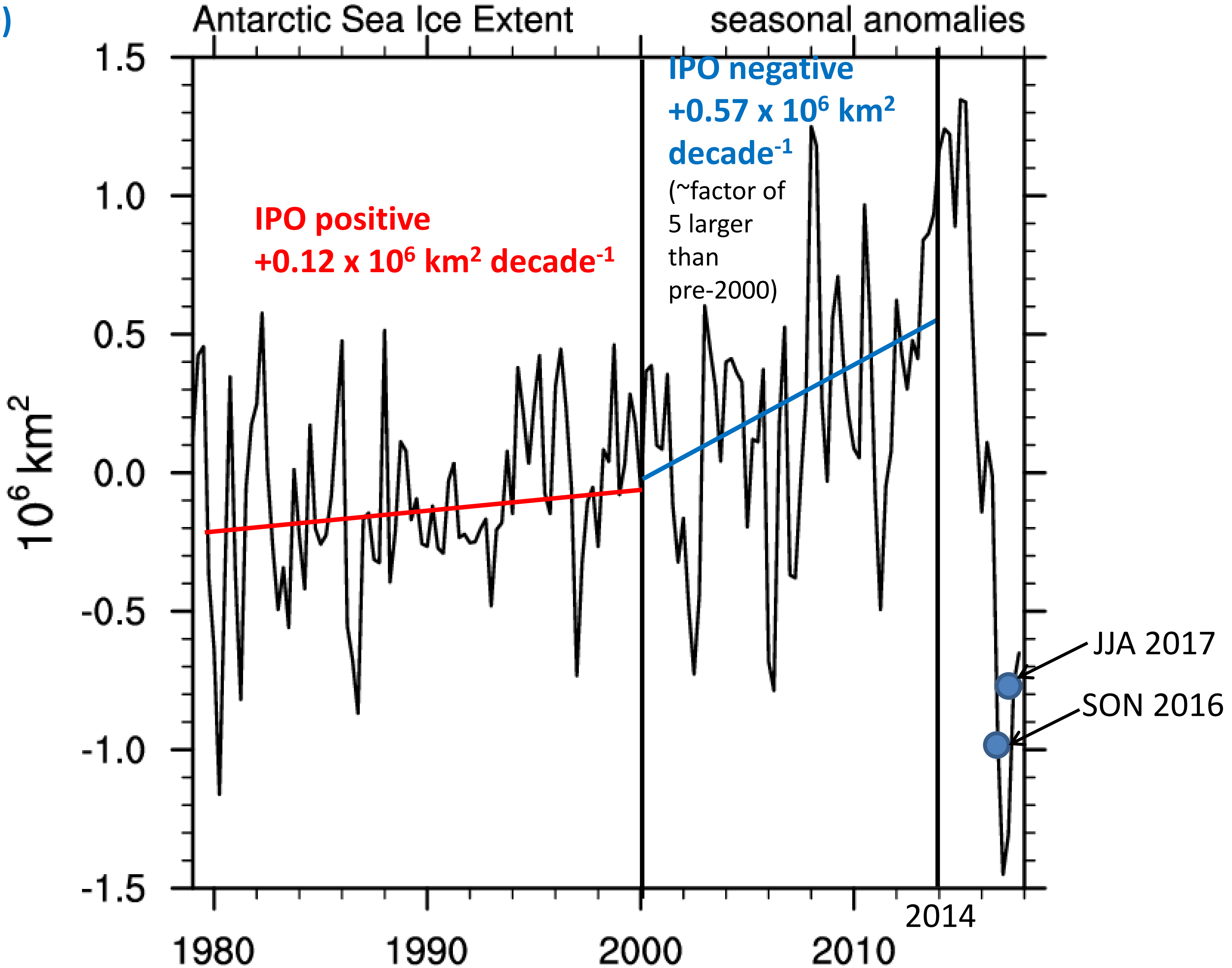
Tropical Atlantic Positive convective heating anomaly

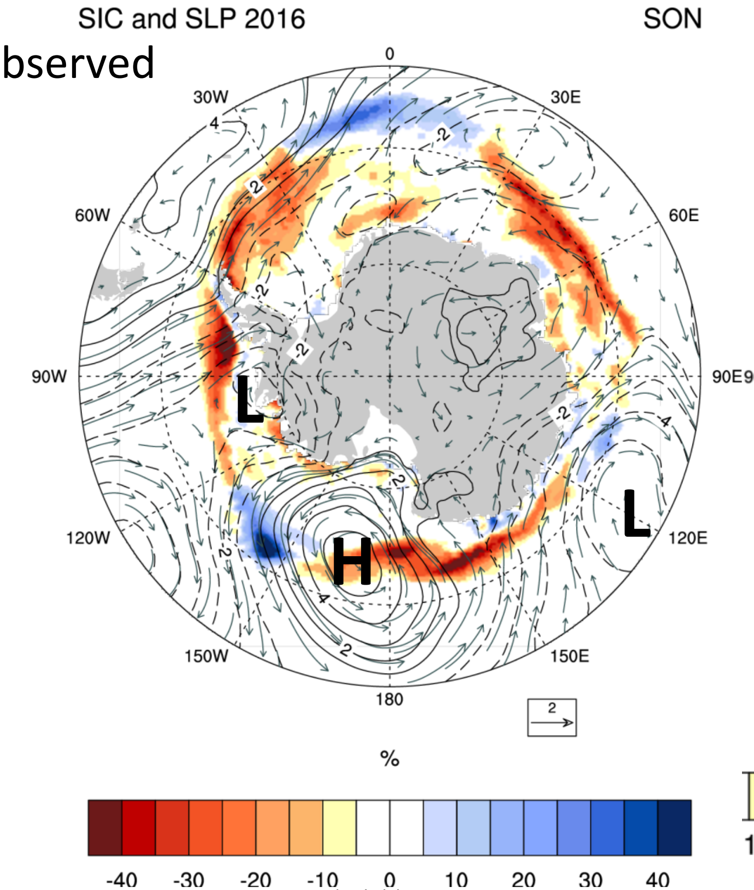
Surface temp

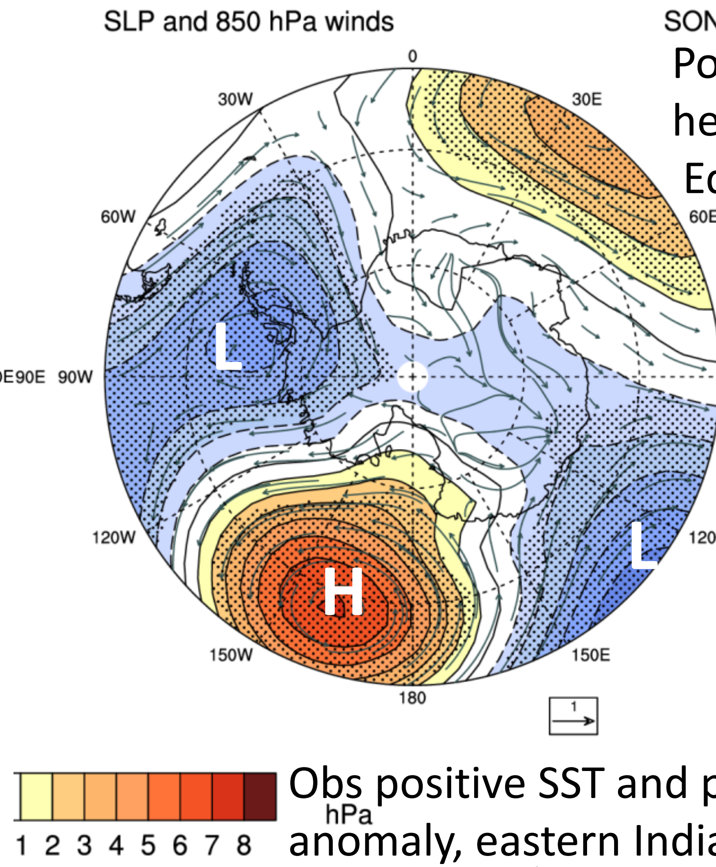


What’s been happening recently in the Antarctic?

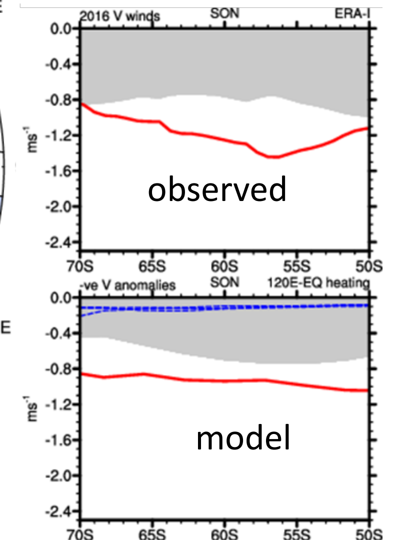
annual mean Antarctic sea-ice extent from 2000-2014 (linear trend of +0.57 x 10^6 km^2 $decade^{-1}$) about a factor of five larger than the increase from 1979-1999 (linear trend of +0.12 x 10^6 km^2 $decade^{-1}$)



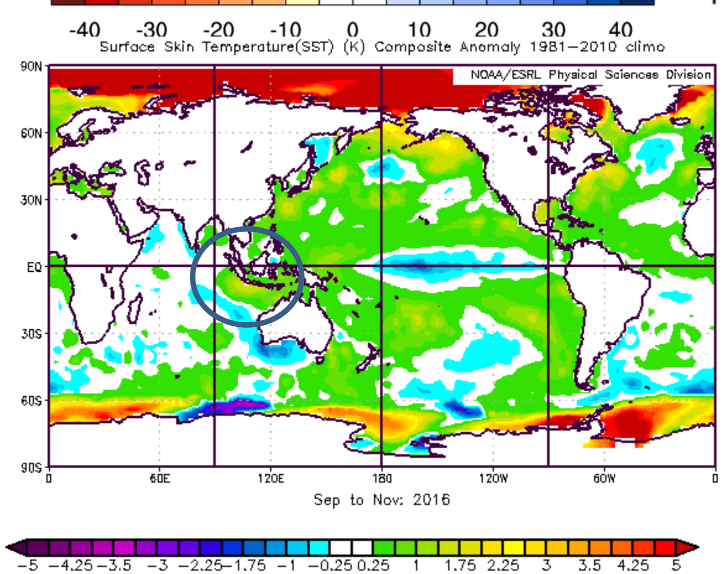


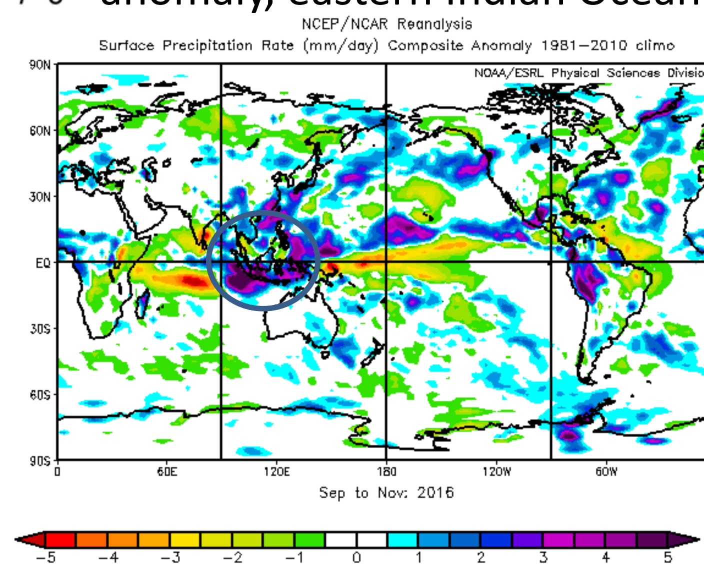


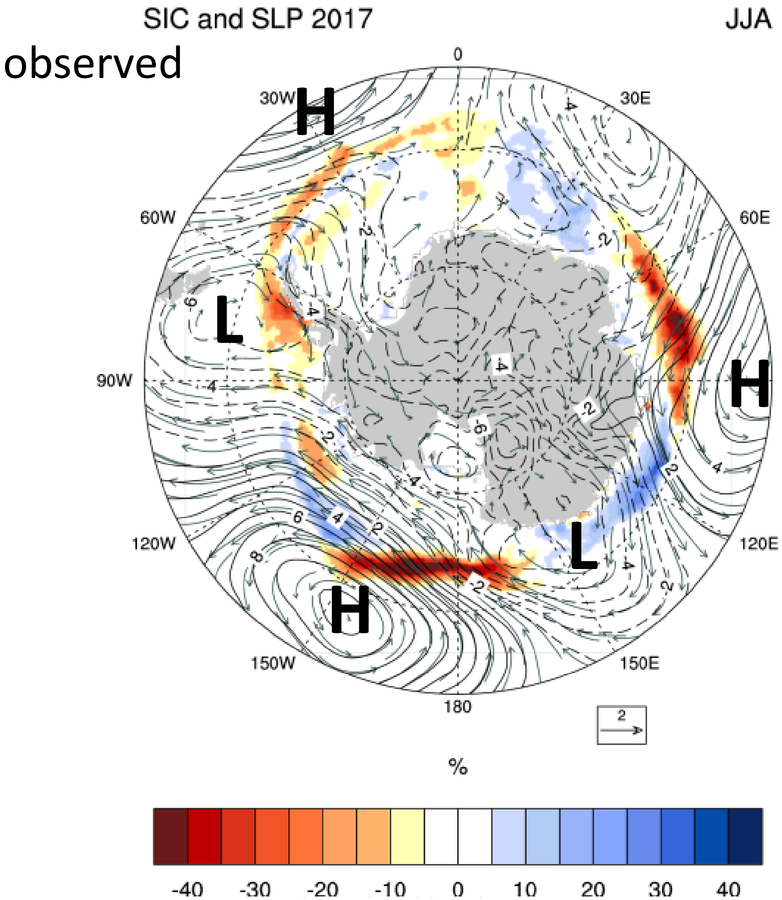
Positive convective heating anomaly at Eq., 120E

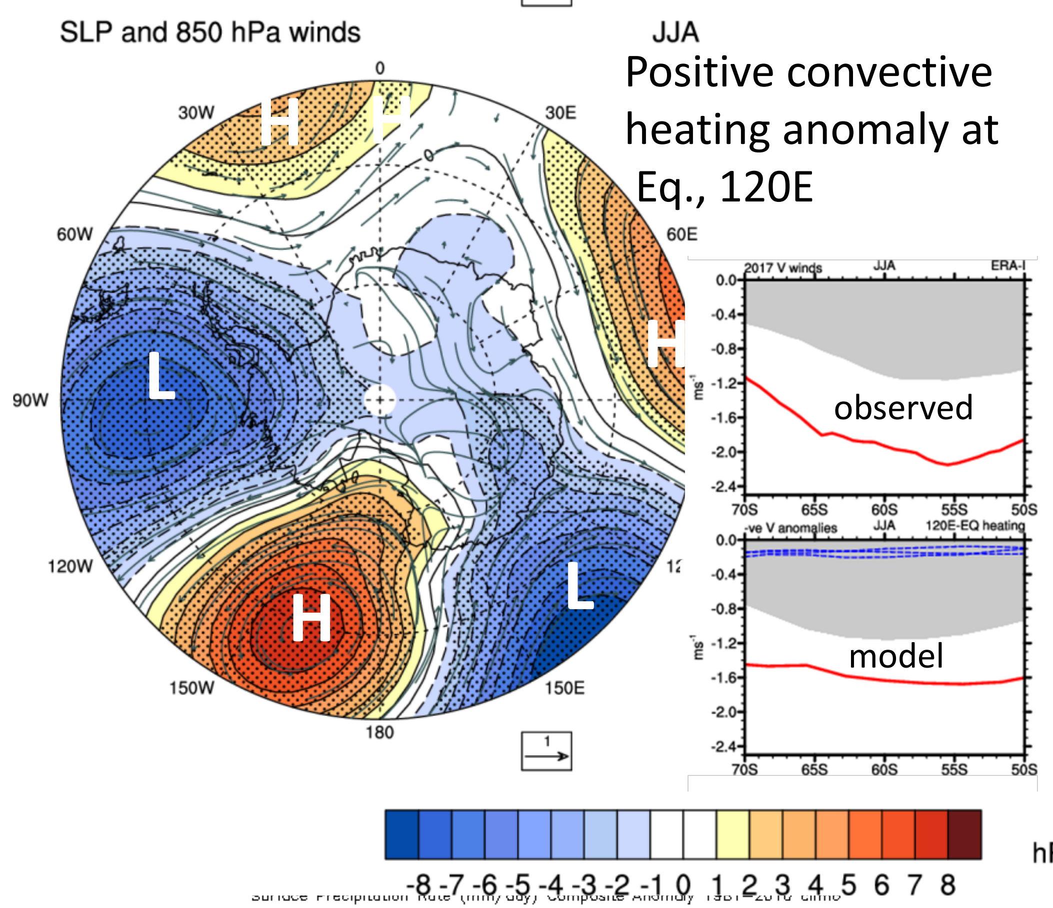


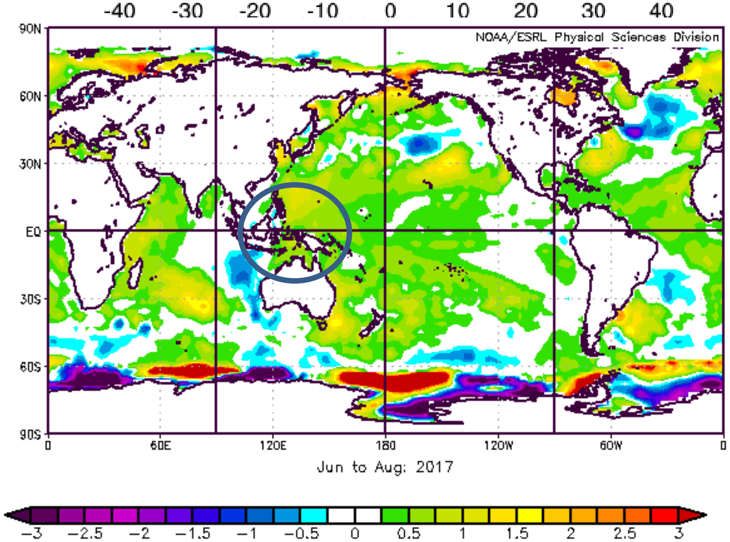
Obs positive SST and precipitation anomaly, eastern Indian Ocean near 120E

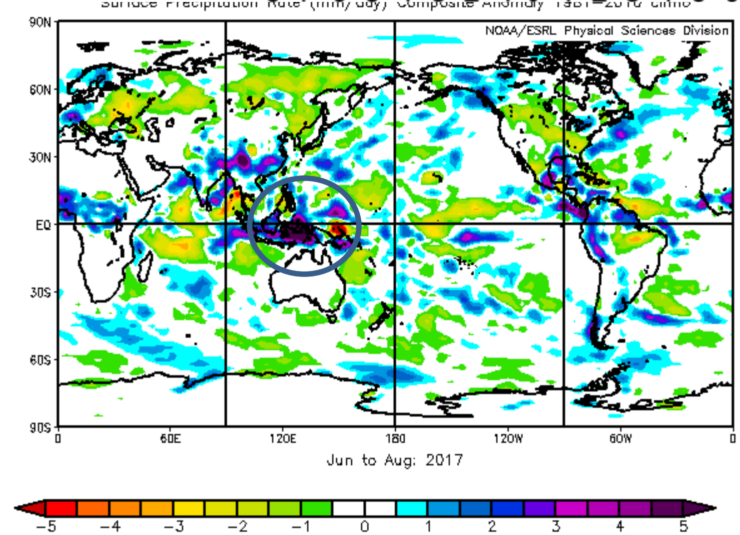





SIC and SLP 2017
JJA
observed
H
L
H
L
H
%
-40 -30 -20 -10 0 10 20 30 40


SLP and 850 hPa winds
JJA
Positive convective heating anomaly at Eq., 120E
H
L
H
L
2017 V winds JJA ERA-I
observed
-ve V anomalies JJA 120E-EQ heating
model
ms⁻¹
-8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8


NOAA/ESRL Physical Sciences Division
Jun to Aug: 2017


NOAA/ESRL Physical Sciences Division
Jun to Aug: 2017

Summary

1. Convective heating anomalies in the tropical Pacific from the negative phase of the IPO drove atmospheric circulation anomalies and a preponderance of northward surface winds around Antarctica that contributed to the increasing Antarctic sea-ice extent from 2000-2014, with secondary contributions from the tropical Atlantic and SPCZ regions

2. Decreasing observed Arctic sea ice extent trends accelerated after about 2000 when the IPO transitioned from positive to negative, and observed patterns of SLP, heat flux and surface temperature trends changed around 2000 in both seasons

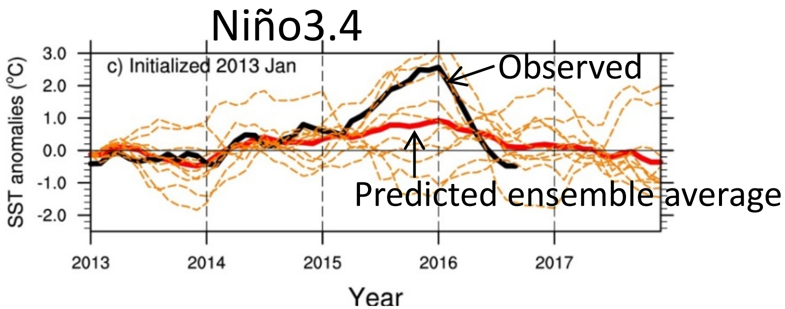
3. For cold season (NDJF) there is a connection to Arctic region circulation anomalies in 2000-2014 associated with negative IPO and negative convective heating anomalies in the tropical Pacific; not so for JJAS

4. For warm season (JJAS) there appears to be a stronger Arctic connection to positive convective heating anomalies in tropical Atlantic observed in association with positive SST trends in that basin in 2000-2014; not so for NDJF

5. Recent decreases of Antarctic sea ice extent, starting in SON 2016, show connection to positive convective heating anomalies in equatorial eastern Indian Ocean and western Pacific

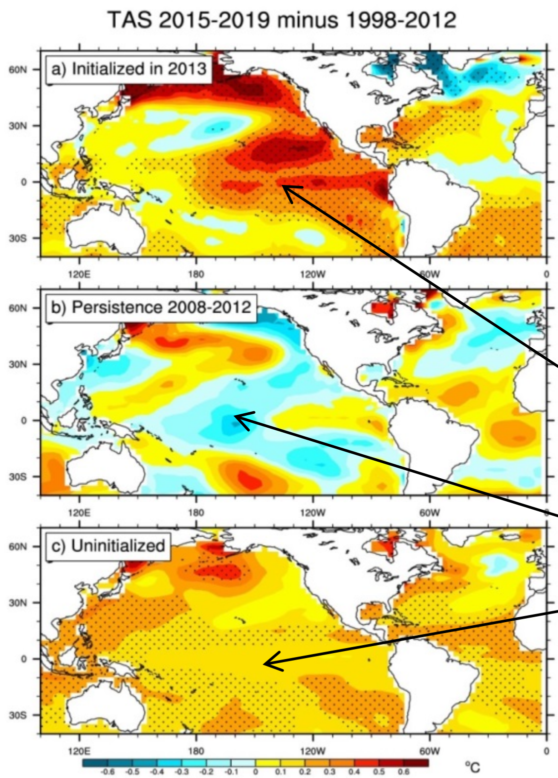
What about the IPO?

Initialized prediction



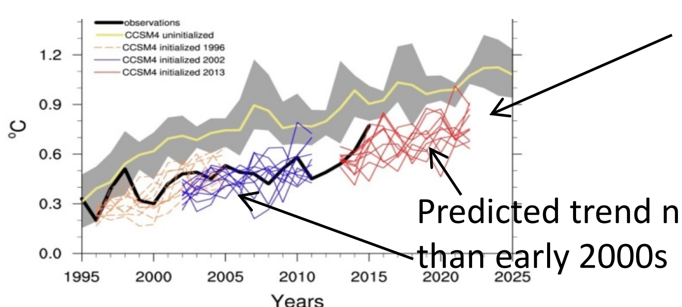
Model initialized in 2013 predicted small warming in 2014 followed by larger El Niño in 2015-2016

Physical basis for prediction skill: Initialized hindcasts show model qualitatively captures ENSO evolution in eastern equatorial Pacific that triggers decadal timescale IPO transitions associated with off-equatorial western Pacific ocean heat content anomalies

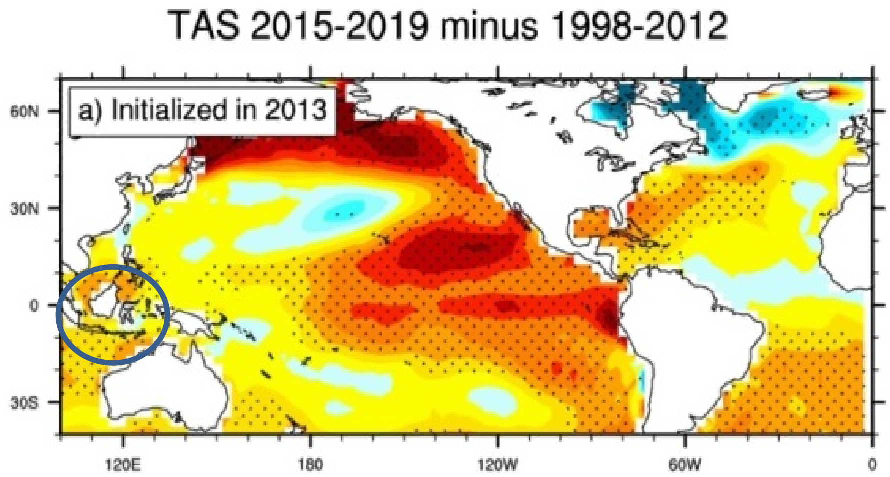


Prediction (initialized in 2013) for years 3-7 (2015-2019) shows transition to positive phase of the IPO different from persistence or uninitialized

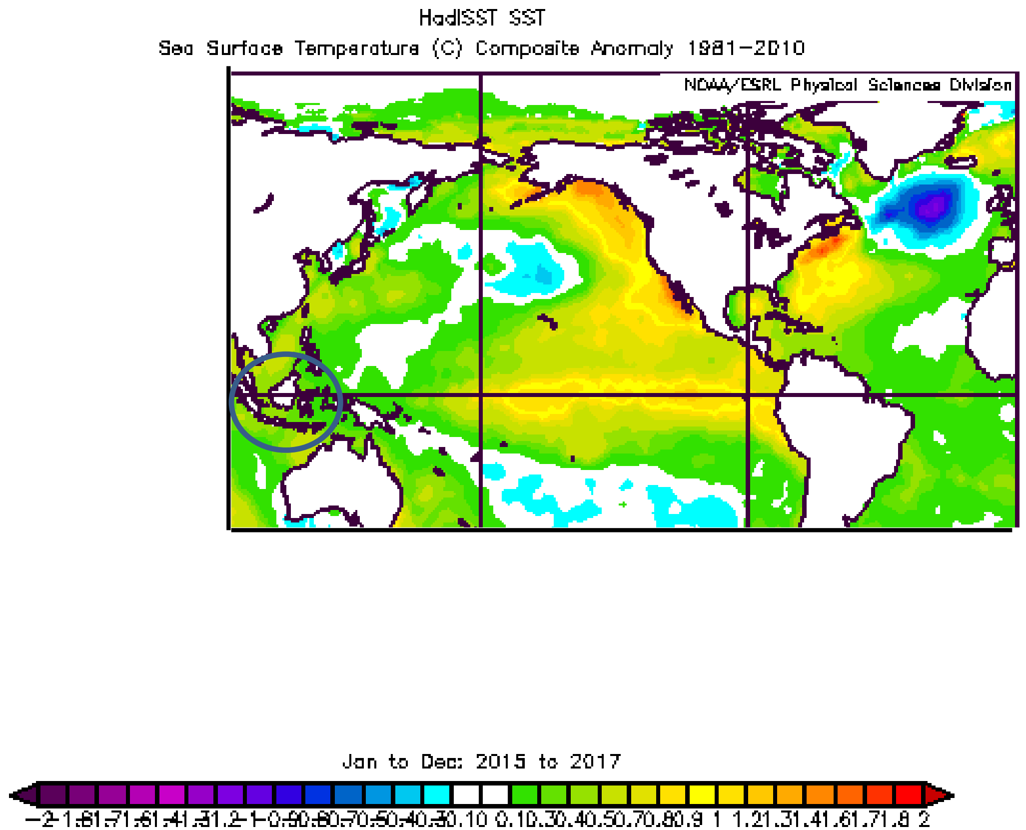
Predicted transition to positive IPO produces global temperature trend for 2013-2022 of +0.22±0.13°C/decade, nearly 3 times larger than 2001-2014 trend of +0.08±0.05°C/decade during previous negative phase of IPO



(Meehl, G.A., A. Hu, and H. Teng, 2016, *Nature Comms.*)



Prediction for 2015-2019 average



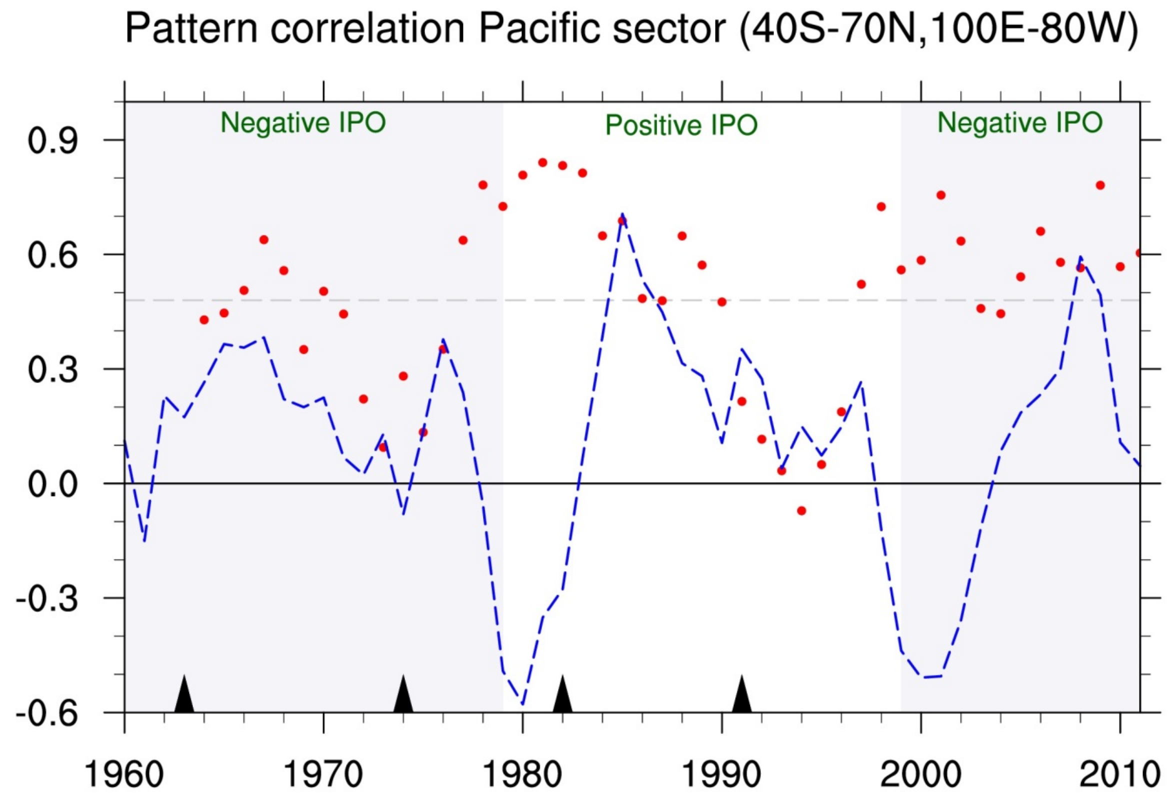
Observed for 2015-2017 average

Why does this matter?

Because we need a process-based understanding of decadal climate variability to evaluate initialized decadal climate predictions

Predictions of decadal transitions of the IPO could provide the process context for some skill in decadal climate predictions

There is skill in predicting Pacific SSTs associated with the IPO in initialized hindcasts in CCSM4

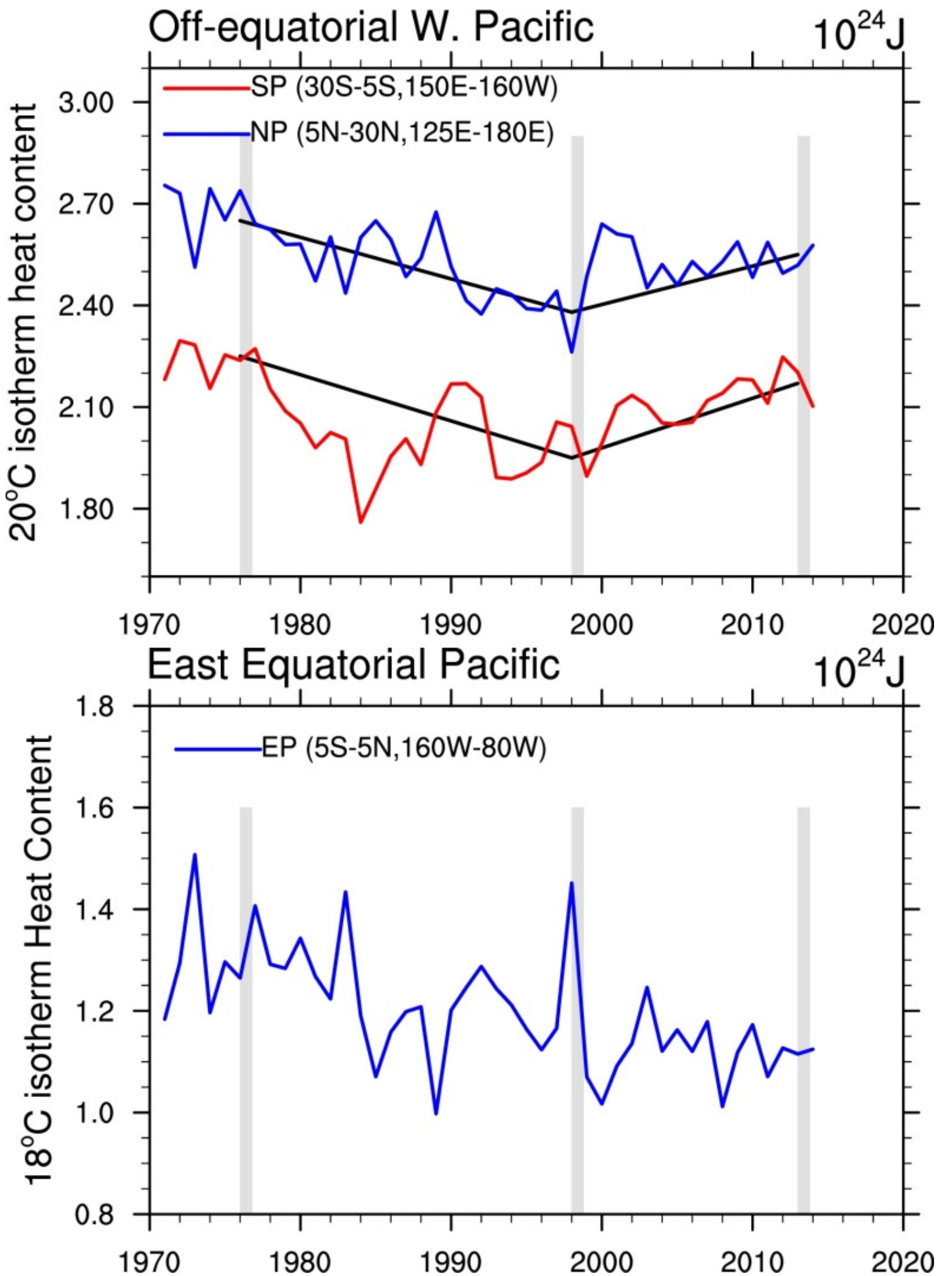


To guard against "false alarms" in future predictions: look at hindcasts of the IPO pattern of SSTs in the tropical Pacific (year 3-7 average predictions, each initial year from 1960, 10 ensemble members for each initial year prediction)

The model shows significant skill except for the early 1970s and early 1990s when the post-eruption sequence of Pacific SSTs after Fuego and Pinatubo did not match the ensemble average model response to the forcing (Agung and El Chichon better matched the model hindcasts) (Meehl et al., 2015, GRL)

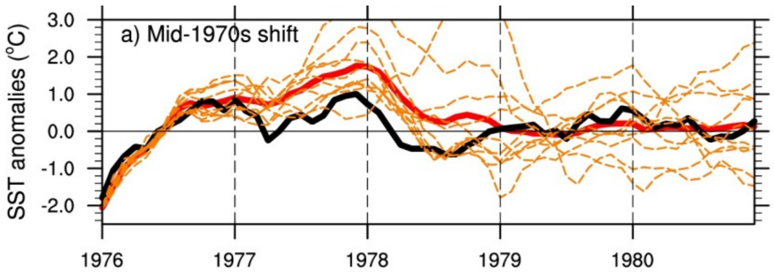
(Meehl, Hu, Teng, 2016, Nature Communications)

Could ENSO events on the interannual timescale trigger decadal shifts of the IPO?



Off-equatorial ocean heat content in the tropical western Pacific can provide the conditions for ENSO events to trigger an IPO transition

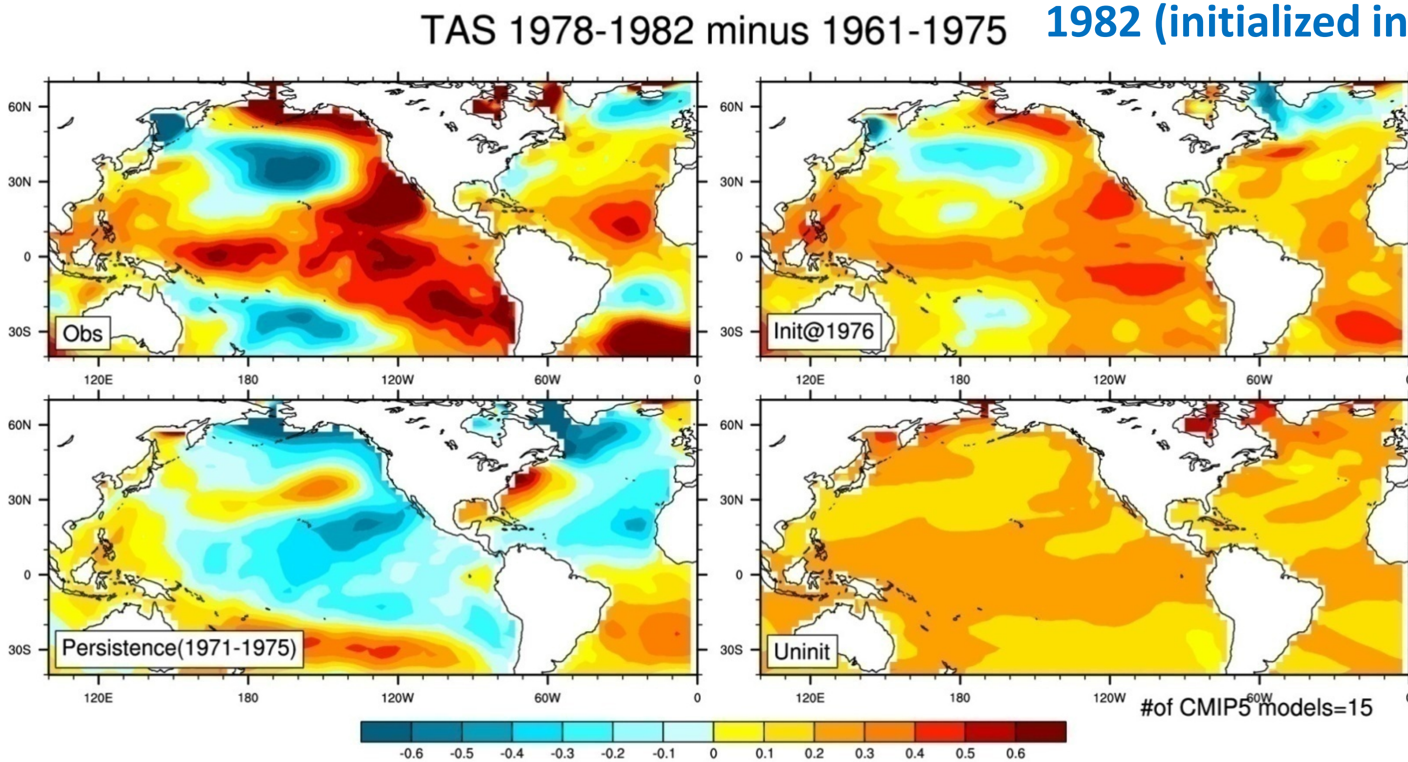
(Meehl, Hu, Teng, 2016, *Nature Communications*)



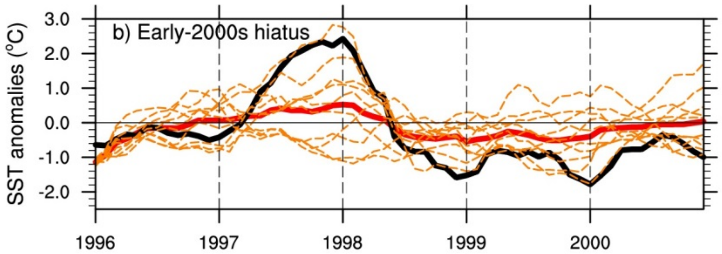
Nino3.4 SSTs, initialized January 1976 (black: observed; red: model initialized in Jan 1976)

Initialized prediction of mid-1970s shift of IPO to positive associated with prediction of 1976-77 El Niño

3-7 year prediction for 1978-1982 (initialized in Jan 1976)



Pattern correlation = +0.81

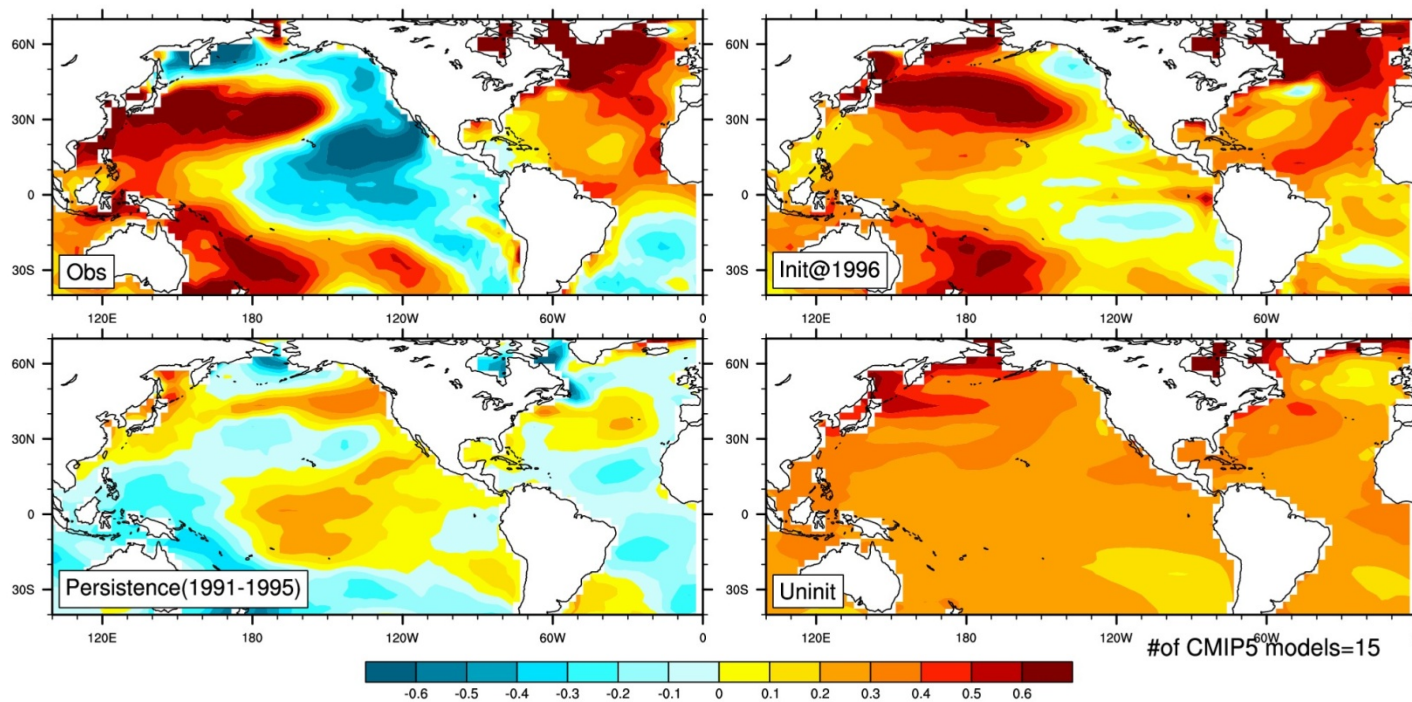


Nino3.4 SSTs, initialized January 1996 (black: observed; red: model initialized in Jan 1996)

Initialized prediction of lat-1990s of IPO to negative associated with prediction of 1998-2000 La Niña

3-7 year prediction for 1998-2002 (initialized in Jan 1996)

TAS 1998-2002 minus 1981-1995



Pattern correlation = +0.59